**Exploring the Feasibility of Switching the Advanced Photon Source Water Cooling System from a Low Dissolved Oxygen Domain to a High Oxygen Domain**

Edward Doherty

University of Illinois Urbana-Champaign

Argonne National Laboratory

Argonne, Illinois

August 6, 2004

Participant: ______________________________
Signature

Research Advisor: ______________________________
Signature

## Table of Contents

## ABSTRACT

Exploring the Feasibility of Switching the Advance Photon Source Water Cooling System from a Low Dissolved Oxygen Domain to a High Dissolved Oxygen Domain. EDWARD DOHERTY (University of Illinois, Urbana-Champaign, Illinois, 61820) Sushil Sharma (Argonne National Laboratory, Argonne, Illinois 60439).

Small diameter and high turbulence water cooling system components for the Advanced Photon Source (APS) accelerator system, such as 1/8" copper tubing, tubing with copper mesh inserts and flow control valves, require time-costly maintenance after openings of the system; these openings very quickly raise the dissolved oxygen (DO) in the water from a normal operating level of 3 parts per billion (ppb) to a level of 500 ppb. Then, over a period of several days, the DO falls back down to the original level of 3ppb once the system runs and deaerates again. This transition from a low to high and then back to low DO level causes dissolved copper in the water to precipitate and clog the troublesome components, decreasing water flow and worsening the cooling of the accelerator components, such as bending magnets and insertion devices. Previous studies have shown the DO level has a direct effect on copper corrosion and deposition, and they suggest that an acceptable operating range (with little corrosion) exists at +2000 ppb, a level at which some other similar facilities already run. A closed loop secondary water system that draws water from the main system will be used first to learn how to control the DO level in the water and to see its effect on the main water system. Once control over DO is established, several trials of transitions from a low DO domain to a high DO domain will be run over varying lengths of time using the secondary system built with the problematic components installed in parallel to measure and quantify the impact of transitions to understand further what currently happens in the system. The components will be precisely weighed just before installation and after each trial to measure copper deposition; the differential pressure across the components will be recorded to measure clogging within the components as well. Should the tests prove transition to a high DO system advantageous, the switchover of the main APS system could result in thousands of maintenance dollars saved and improved reliability, as the equipment for DO removal would be unnecessary and the components would require fewer cleanings.


**Category: Mechanical Engineering**

Considered for publication in the DOE Undergraduate Research Journal: NO
School Author Attends: University of Illinois Urbana-Champaign
DOE National Laboratory Attended: Argonne National Laboratory

Mentor's Name: Sushil Sharma
Phone: (630) 252-6820
Email Address: sharma@aps.anl.gov

Presenter's Name: Edward Doherty
Mailing Address: 534 Castle Court
City/State/ZIP: Bolingbrook, IL 60440
Phone: (630) 739-6164
Email Address: epdohert@uiuc.edu

# INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Laboratory in Argonne, Illinois is a synchrotron that produces the nation's most brilliant x-rays for use in research of material science, biology, chemistry, and physics. The accelerator uses about 10 MW of power, and to keep the system temperature in working range, a water cooling system runs throughout many of the copper components of the accelerator, such as its magnet conductors and storage ring absorbers. The system includes a slipstream water-polishing station that removes as much dissolved copper and other ions as possible (bringing resistivity to ~10 M**Ω**; the water is thus deionized), filters to keep the water clean, and deaeration equipment to remove dissolved oxygen (DO).

When the facility was initially started, the effects of DO on copper corrosion and agglomeration were not realized. The water system had a deaerator that effectively kept the system at about 200 parts of oxygen per billion (ppb). The system experienced copper corrosion with cuprous oxide deposits in certain components, but as time progressed, the deposits became more pronounced [1]. Studies into the effects of DO on corrosion and agglomeration [2] revealed that a DO regime of <10 ppb or >2000 ppb would have much less corrosion. The system was subsequently upgraded to reduce the operating DO regime to <5 ppb, which is where it currently runs. It was felt that an upgrade to the system was more prudent since the original contractors suggested a low DO regime for the polishing loop, and the deaeration process had already shown to work well enough.

Despite having the system upgraded, agglomeration still occurs, gradually clogging components over months. The water components most affected are small diameter tubing and tubes with a copper mesh insert (the mesh improves heat transfer). Flow control valves produced by Griswald [3] also experienced trouble, but almost all of them have since been replaced in the system. Whenever the system is exposed to air through maintenance or accident (opened), the DO rises very quickly to levels of 500 ppb and beyond (depending on the nature of the opening). After the system is running again, the DO level falls back to normal operating level (<5 ppb) over several days. During this period of the DO falling to normal (figures 1 and 2), the pressure differential across the Griswald valves dropped, as shown in figures 3 and 4, indicating the flow through the components decreased from copper deposition and clogging. This buildup during a transition causes the maintenance staff to have to flush out many of the copper components during a shutdown period, which is a very costly and time-consuming process.

A high DO regime, however, would not encounter this problem, because whenever the system is exposed to air, the DO level will not change very much; the water is already saturated with oxygen, and no clogging will occur since the DO level will not pass through the undesirable middle region (80-700ppb) of the copper corrosion curve as displayed in figure 5 [2]. A high DO regime has a comparable amount of copper corrosion as the low DO regime based on studies done at electric power plants, whose water system conditions are similar to those at the APS. Many of these power plants as well as several synchrotron facilities already run at a high DO level and do not experience the problems currently affecting the APS.

The purpose of the project laid out in this paper is to investigate the nature of the DO transitions on the copper deposition process and to highlight any problems that may arise if the APS system were to implement a high DO regime.

## MATERIALS AND METHODS

To run several trials of transition experiments that accurately represent what the APS system would experience, water needs to be extracted from the existing system to insure the resistivity, copper content, and pH of the test water equals that of the system; all of these factors could affect deposition. The experiment will use a constant supply of water from the system which must be returned to the system; the returning water will have a high DO level, but it must not raise the system's DO level appreciably. If the system experiences a significant (>5 ppb) change, oxygen-scavenger tanks must be installed in the experimental setup to reduce the DO in the returning water. The temperature must also be regulated as the copper solubility is affected by temperature [2].

For the experiment, a closed loop skid that was once used by one of the beamlines will be used. Permission has already been obtained for using the skid for beamline #2; it consists of an open-air tank with a heat exchanger, a pump, filtration, and several gauges (see figure 6 [4], 8, and 9). In the tank, an oxygen diffuser connected to an air compressor (or bottled air) will be installed, and a bubbling device most commonly used in water treatment plants. The bubbling device works just like an air stone for an aquarium by making a cloud of tiny bubbles that maximize the surface area to volume ratio for maximum oxygen diffusion into the water. With this device, the DO can be brought up extremely quickly in the skid system. To measure the DO, Orbisphere probes [5], the same kind currently used in the system, are to be used at key junctures. The components to be installed in a parallel array to represent the parts of the system that get clogged are the most problematic components: 1/8”- diameter copper tubing and ½” copper tubing with a copper mesh insert, and Griswald flow control valves. They will be first weighed on a highly accurate scale (for comparison with after a trial), and then installed in a manifold with up to thirteen branches available to run up to 13 of these components (see figure 7 for a sketch of the setup). For every trial run will have the same number of the same type of components for consistency.

A closed loop skid was chosen for the experiment for use as a slipstream, because it was felt a slipstream could offer most control over the DO level by mixing the water in different amounts, and it would be simple to disconnect the aerating part of the experiment in case anything were to go wrong. The water intake for the slipstream is taken from the supply to the beamline for clean water, and the return is put into the return side of the secondary system, so that all the oxygenated water is going to the utility building for polishing, rather than going into critical components. Oxygen meters by Orbisphere are used because they will monitor the oxygen in the skid and several feet after the high DO water mixes with the low DO water to ensure proper mixing. The components chosen are those that have experienced the worst of the copper deposition and would indicate copper deposition the most, creating a stark contrast that is readily apparent. There are more opportunities to see the copper deposition with a greater number of components, but beyond 13 components, the array becomes large and difficult to place.

To begin the experiment, control over the DO level must be gained, as well as experience as to how quickly DO levels change and what actions would have what effects. The skid is made as a closed loop and filled with water; the DO level would read as the natural saturation level. Then the skid is run with the oxygen diffuser on maximum air pressure, putting as much oxygen into the water as possible; this gives the upper limit of how high the DO could be made to go.

After equilibrium states are determined with and without aeration, the skid is hooked into the APS water system. Now the skid acts as an aerating slipstream, where water from the skid is returned in controlled amounts from a valve to control the DO level that runs through the component array, which does not have any components installed yet. Now the flow into the skid is equal to the return (so as to prevent the skid from overflowing), and the flows are experimented with to investigate how different flow rates mixing with the system affect the DO level that results in the component array. DO levels throughout the APS system should be carefully watched to make sure the project does not adversely affect the system. If the DO level rises above 10 ppb, the skid will be shut off from the system immediately. After working with the valve controls and getting an idea of how the slipstream flows affect the DO after mixing, precision control over how to attain desired DO levels will be realized, and the project can proceed to the transition trials.

The transition trials, the heart of the project, will be run forwards and backwards; after the components are installed and low DO water flows through the array, the DO level will be brought up from ~3 ppb to the maximum DO level over a period of 5 days. The meters will be carefully monitored, the components weighed, flushed, and weighed again after the 5 days (for analysis), and then the next trial will be begun: from high DO to low DO over 5 days. After analysis and cleaning, the next two trials will be run much faster, with the transition taking place over 12 hours.  One trial runs from low DO to high, and the other trial is from high to low, with analysis and cleaning after each trial.

## RESULTS

The results of the experiment will consist of differential pressure readings and the amount of change in mass of the components.  When the pressures across the components increase, this will indicate further clogging and restriction of flow; a decrease will indicate that whatever deposits existed before are now dissolving back into the water. The change in weight would indicate how much copper is accumulating in the components, and is another measure of how badly the clogging occurs; a greater change in weight means more copper deposited.  Results also to be noted are how quickly the skid system becomes aerated, how the system is affected by a known amount of fully oxygenated water being introduce, and how much fully oxygenated water is required to be mixed with low DO water to achieve a desired DO level.

## CONSEQUENCES AND CONCLUSION

The trials will prove whether copper deposition actually takes place while the DO is increasing from a low DO level to high or whether it actually happens when it is brought back down again.  They will also demonstrate whether a quick transition is more beneficial than a slow transition, and how badly the components will be affected by the transition.  If the study reveals severe deposition for both trials of aerating from low to high DO, then it may prove that the switchover of regimes would be too much risk.  The system has many components, and if they were all to be clogged and required a massive effort to clean before operations could be resumed, then the switchover would not be implemented.

Should the investigations prove a transition from a low DO to high DO relatively free from deposition, the benefits to the APS will be substantial in effort and cost. The system would require fewer (if any) flushings of components, there will be no significant change in DO levels every time the system is opened. The water system would also become more reliable, as the DO level will be in a stable state that does not require constant vigilance. Third, the deaeration system, a costly system to operate, would be decommissioned, replaced by aeration tanks that maintain the DO level in its elevated state. Previous studies and experience indicate that a closed system's DO cannot be maintained at a high level because of the corrosion process [2].

## ACKNOWLEDGEMENTS

I would like to thank Sushil Sharma, the ME Group leader here at the APS and my mentor, for giving me a project from the ground up and a chance to see the working world of engineering. Thanks to Eugene Swetin for being there and figuring out with me what to do with this project from the ground up, and for improving my scanning and Excel skills through mass repetition. Thank you Hector DeLeon for making sense of the arcane sketches of the water systems and for putting so much effort into getting things running in the very limited time. Special thanks to the rest of the ME Group and technicians for working with me and proving how collaborative effort is required to make things happen. And finally I would like to thank Argonne's Department of Educational Programs for taking in students and turning their boring summers into an educational experience of great value.

## REFERENCES


[1] R. Dortwegt, C. Putnam, and E. Swetin, "Mitigation of Copper Corrosion and Agglomeration in APS Process Water Systems," 2nd Int'l Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI2002), Sept. 5-6, 2002, Argonne, IL, pp. 462-468 (2003).

[2] R. Dortwegt, "Low-Conductivity Water Systems for Accelerators," Proc. Of the 2003 Particle Accelerator Conference, Portland, OR, USA, May 12-16, 2003, pp. 630-634 (2003).

[3] Griswold Controls. http://www.griswoldcontrols.com

[4] J. Collins, "Technical Specifications for the Mezzanine Closed-Loop DI Water Production/Distribution System," APS/XFD/BEC Technical Document, November 20, 1997.

[5] Orbisphere, subsidiary of Hach Ultra Analytics. http://www.orbisphere.ch

**Figures**

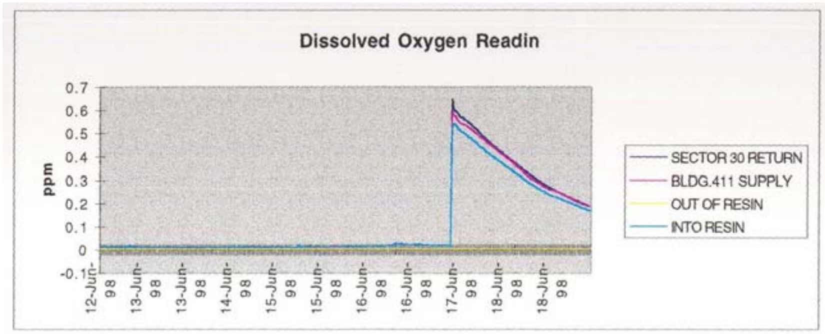


Figure 1. DO readings from throughout the system during an accident that released DO into the system.

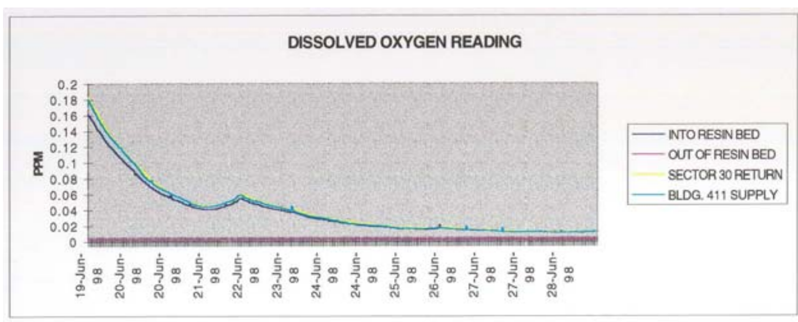


Figure 2. DO level readings continuing from figure 1. Note the change in scale.

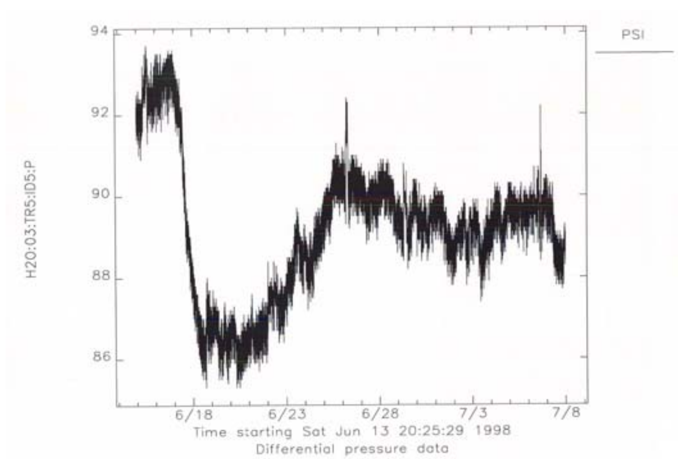


Figure 3. Differential pressure readings across a Griswald valve in sector 3 during the accident.

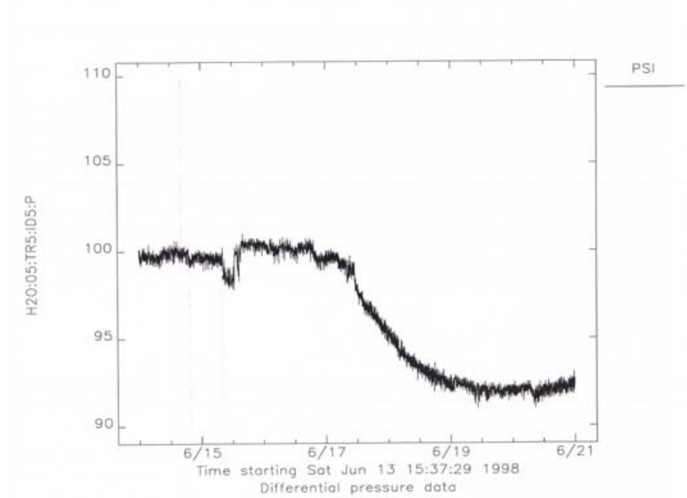


Figure 4. Another differential pressure reading across a Griswold valve in sector 5.

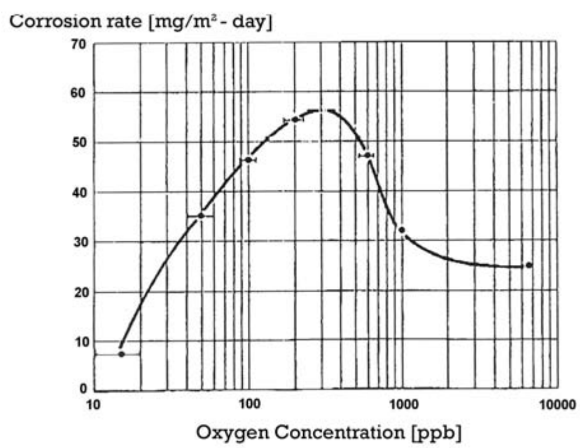


Figure 5. Copper corrosion rate vs. DO.

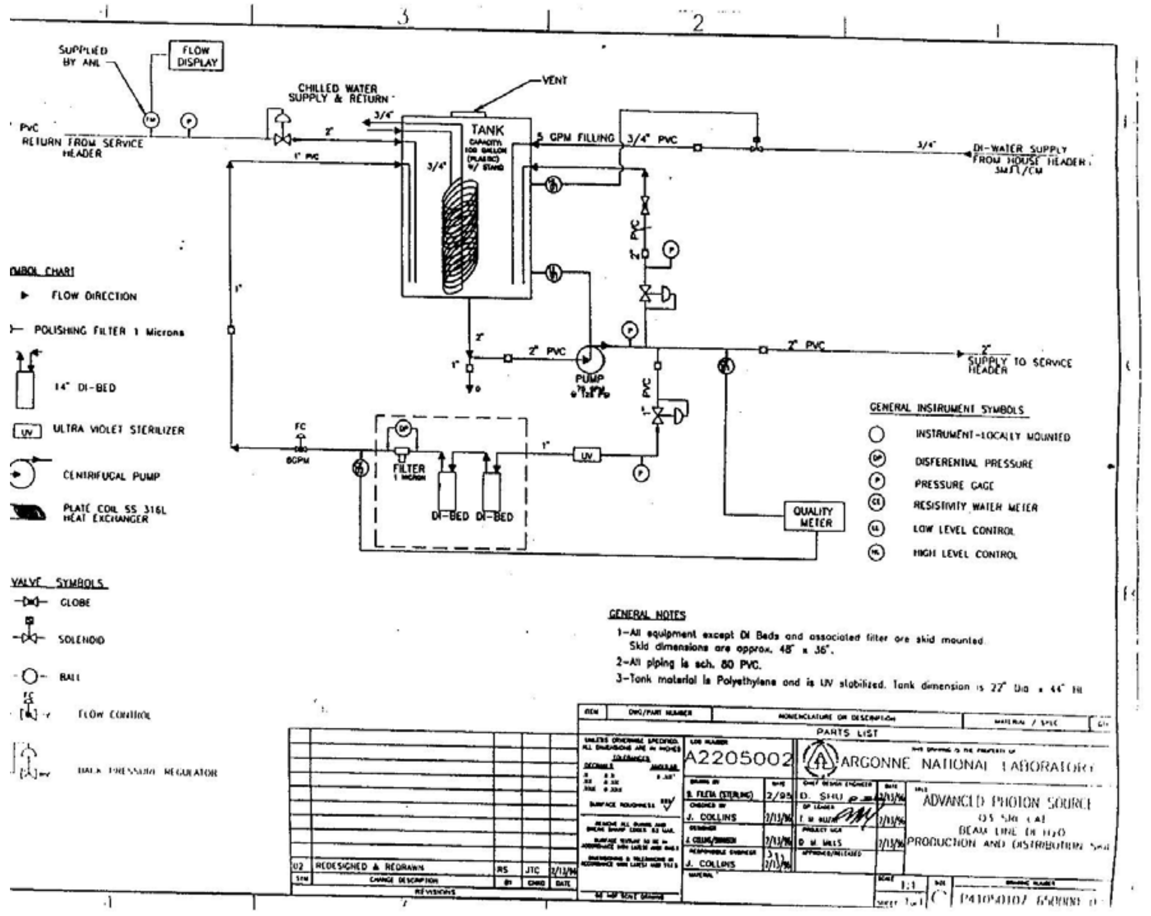


Figure 6. Schematic drawing of the beamline skid.

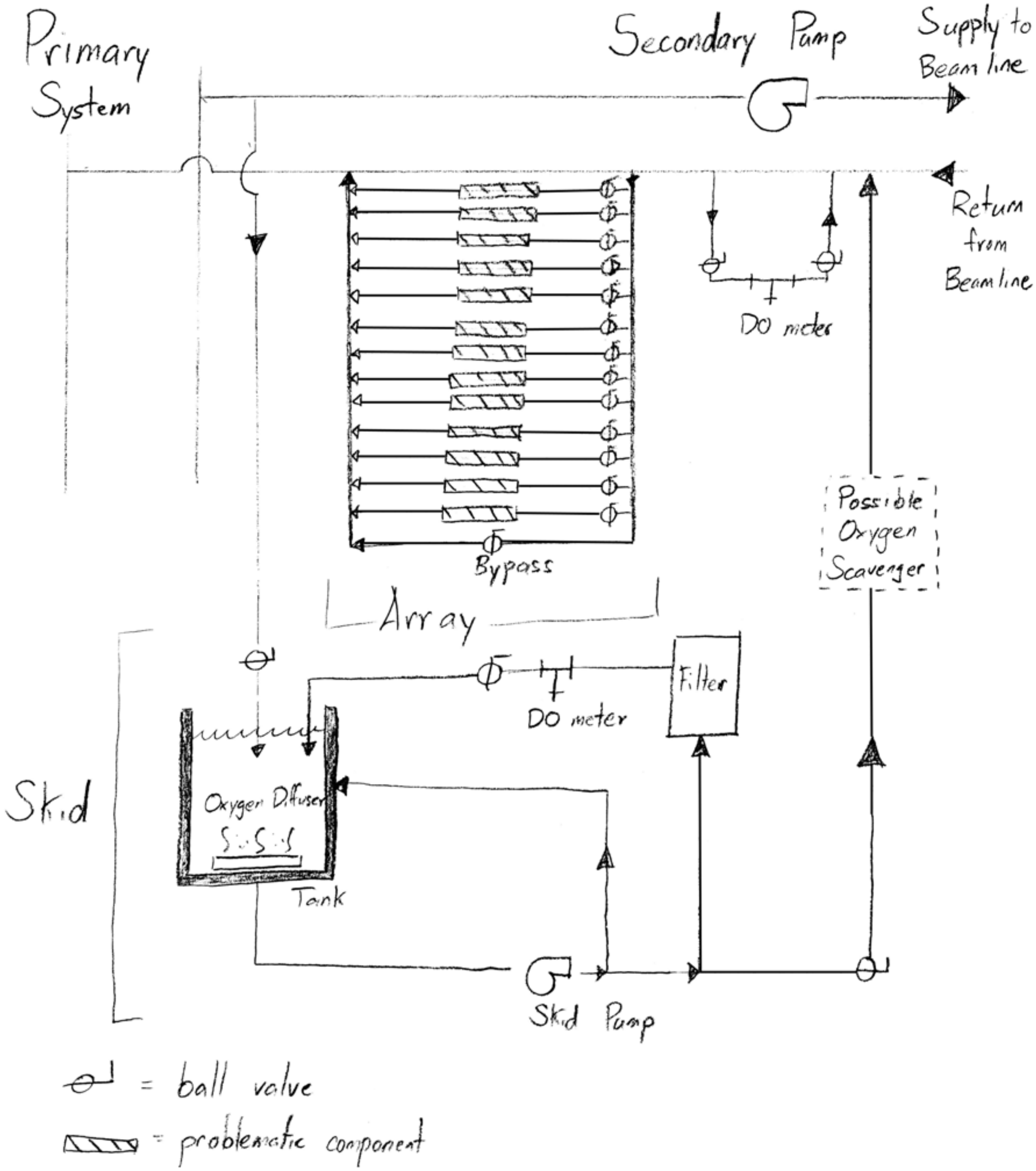

Figure 7. Experiment setup drawing.

Figure 8. Picture of skid used by beamline #2.

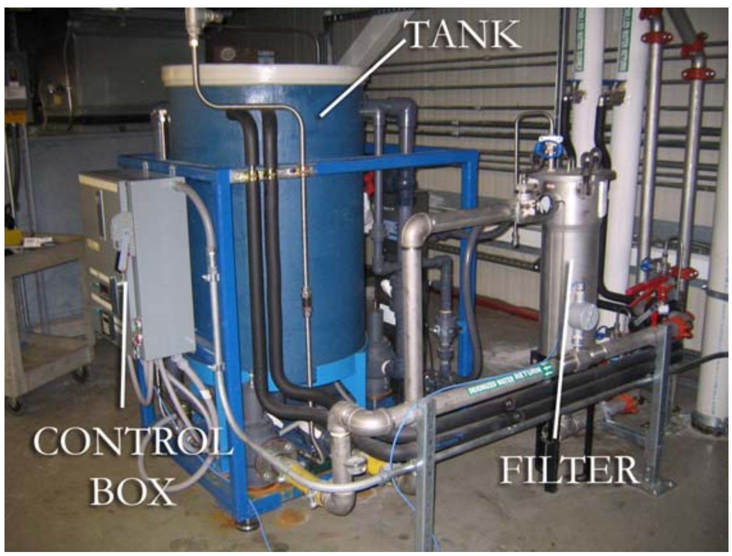


Figure 9. Another picture of the skid used by beamline #2.